An Illumination of the Roles of Hands-On Activities, Discussion, Text Reading, and Writing in Constructing Biology Knowledge in Seventh Grade

Carolyn S. Wallace
The University of Georgia

A previous study (Wallace, Yang, Hand, & Hohenshell, 2001) indicated that seventh-grade life science students using a learning tool known as the Science Writing Heuristic (SWH) performed significantly better on conceptual test questions than did a control group. In the present study, the researcher studied more deeply how students utilized a variety of knowledge sources while engaged in the SWH, including textbook, teacher-led discussions, laboratory activities, peer group discussion, and writing (including their cognitive mechanisms and the nature of their written explanations). Six case students were selected based on a range of high to low achievement according to grades. An interpretive analysis of interview and document data was conducted. Of the 6 students, 3 relied on firsthand observations from laboratory activities as their major source of understanding; these students used listening, explaining, and writing most frequently. One student relied solely on textbook and teacher statements and actively rejected laboratory observations, relying primarily on reading and synthesis. Two students integrated laboratory observations with canonical information found in the textbook and other reading sources. They were able to bridge between the different epistemological bases for firsthand observations and authoritative text and blended these into rich and detailed explanations for biology concepts.

Scholars interested in writing to learn in science have been pursuing parallel paths toward understanding the cognitive and metacognitive mechanisms involved in the learning process. In one path, researchers have identified hypotheses to explain learning through writing and are testing these hypotheses to support or disconfirm the importance of various psychological mechanisms (Galbraith,1992; Klein, 1999; Wallace, 2000). Within a second pathway, researchers are engaged in classroom work to investigate strategies that are efficacious for producing enhanced conceptual knowledge and nature of science understandings (Keys, Hand, Prain, & Collins, 1999; Mason & Buscolo, 2000; Rivard & Straw, 2000; Wallace, Yang, Hand, & Hohenshell, 2001). Taken together, these research efforts are bringing us closer to an understanding of (a) the cognitive and metacognitive mechanisms of learning science through writing; (b) the way instructional tasks and environmental conditions influence these mechanisms; and (c) the way productive writing tasks and conditions can be implemented in the science classroom.

The current paper examines the links among students' sources of conceptual knowledge, mechanisms for making meaning of conceptual knowledge; and the nature of students' written explanations. The research takes place in the context of instruction using the Science Writing Heuristic (SWH; Keys et al., 1999). The SWH is a tool for generating teacher and student activities to promote understanding of laboratory through social constructivist means. Previous research by the authors (Wallace et al., 2001) indicated that seventh-grade students using the SWH performed significantly better on multiple choice and essay tests for conceptual understanding than those not using the SWH. The purpose of the current study was to probe seventh-grade students' thinking to determine more specifically the cognitive and metacognitive mechanisms operating while engaged in various knowledge negotiation activities of the SWH. The research questions included (a) What sources of knowledge were most useful to students in creating biology explanations? (b)Which cognitive mechanisms did students identify as helping them construct biology understanding? (c) How do students' written biology explanations fit the evidence from students about their own learning?

A complete description of the SWH, the criteria used for its creation, and an explanation of the

psychological and epistemological frameworks, underlying it, may be found in Keys et al. (1999) and Keys (2000). Briefly, the SWH is a heuristic guideline designed to promote the negotiation of meaning for laboratory activities. It is a device similar in some ways to Gowin's Vee heuristic (Novak & Gowin, 1984), but differs in that it includes activities for the teacher and emphasizes the production of ideas in verbal symbols both in talk and writing. The SWH is designed to be flexible, so that the teacher may adjust it to fit the local classroom situation. An outline of the SWH may be found in the appendix. It contains both teacher and student templates.

The SWH suggests to the teacher that concept mapping, question brainstorming, personal writing, group writing, and group discussion may accompany laboratory activities. To students, it suggests that a careful consideration of their authentic questions, their lab procedures, their observations, their claims, and their evidence will help them understand the laboratory material. It additionally asks students to reflect in writing on how their laboratory findings compare with authoritative information (such as that found in their textbook) and on what they have learned from the experience. In the current study, the teacher involved the students in all the teacher template activities and used the student template as a basis for individually written laboratory reports at the close of the investigation.

Because the SWH asks students to compare their own lab findings with authoritative information in the textbook, it implies that students should attempt to compare and contrast these multiple sources of information. These two sources of knowledge (e.g., firsthand observations and textbook statements) represent very different epistemological origins. Firsthand observations are singular and personal and can be interpreted only through the lens of theory (Millar, 1998). Textbook information represents produced bodies of knowledge validated by the scientific community over time. Epistemological origin is just one way these sources of knowledge differ. Another is the type of discourse used around them. Children may talk about their hands-on activities using informal language (M. Templin, personal communication, January 2002). Through the SWH, they are learning to mold their informal speech into slightly more canonical forms, as when they are asked to make claims and evidence. The style of discourse used in textbooks is unique to science, systematic, stylized, and notoriously difficult for students to negotiate (Halliday & Martin, 1993). Thus, one goal of this study was to investigate how children interpret this seemingly difficult task of comparing their own firsthand observations to authoritative information. This is a point to which we had not previously paid attention in the SWH and is one that may greatly affect its efficacy.

Although many studies of writing to learn in science have been conducted in the past (Rivard, 1994), only recently have specific factors contributing to improved conceptual understanding or written science explanations been investigated. Mason and Buscolo (1998), for example, found that fourth-grade students in an experimental writing group reached scientifically acceptable understandings of the targeted concepts for photosynthesis and more advanced awareness of their own cognitive and metacognitive strategies. The writing group also demonstrated an increased understanding of the power of writing itself for exploring science concepts. Klein (2000) found that the following factors contributed significantly to improved written explanations for upper elementary students engaged in hands-on activities: (a) searching text, (b) searching information from experiments, and (c) brainstorming ideas. His results indicate that there are no interactions among these factors; each is a unique strategy that contributes independently to the writing process. Thus, rigorous research studies indicate that writing does contribute to conceptual understanding and that searching for information (seeking evidence) and brainstorming are important factors for improved written explanations.

Over the last two decades, researchers have become increasingly interested in the interplay between science conceptual learning and a variety of affective and cognitive factors, including personal learning frameworks (Hogan, 1999), learning beliefs, and epistemologies (Edmondson & Novak, 1993; Tsai, 1998, 1999). These researchers posited that students with a more traditional view of science, regarding science as a body of knowledge to be discovered by empirical means, will also have more rote strategies for learning science, including memorization and problem practice. Those with a more constructivist epistemology, regarding science as a creative or invented endeavor that changes over time, will use learning strategies such as making connections, imagining an experiment, explaining, etc. It is further posited that those with a constructivist epistemology and learning beliefs will be more successful with meaningful learning (Edmonson & Novak, 1993; Tsai, 1998) and, therefore, more readily build their conceptual knowledge bases. In the current study, student beliefs about the nature of science were not investigated, nor were the students questioned directly on their epistemologies. However, in the interviews, the students were probed on what they believed were their

most salient sources of knowledge while engaged in the SWH activities and what cognitive and metacognitive mechanisms they used in negotiating understanding. Through data analysis, some idea of the students' learning beliefs were captured, as well as their personal epistemologies for learning science during SWH activities. These personal epistemologies were then related to the nature of their learning, as evidenced in written explanations about diffusion and osmosis.

Methods

The study took place in the context of a seventh-grade life science class taught by one teacher in a Midwestern, suburban middle school. Data were collected during two units, one on microorganisms and one on cells. Only data on cells are reported on here. An interpretive research approach was used, because the researcher was interested in understanding science learning from the point of view of the learners. A sample of 10 target students was chosen by the classroom teacher for in-depth study, based on the criteria of willingness to volunteer, balanced gender representation, and a range of science achievement as indicated by course grades. Five male and 5 female students were interviewed. One student was Asian American; 1 was Latino. The remaining 8 students were Caucasian. From the corpus of data for all 10 students, data sets for 6 students were analyzed completely. Further analysis revealed no new emergent patterns. These six data files were chosen based on balanced gender, balanced high, average, and low achievement, and a variety of emergent learning strategies represented. The 6 participants included MF (a high achieving Latino female), AB (an average achieving White female), CW (a low achieving White female), JM (a high achieving White male), AS (an average achieving Asian-American male), and MR (a low achieving White male).

Data sources included semistructured interviews with the students and documents, including students' SWH lab reports, letter writing activity, and pre- and posttest conceptual (essay) questions. The interviews took place in the media center during class time. The researcher interviewed each child individually. The purpose of the interview was to determine from the participants' point of view (a) which activities were most helpful in learning biology during the SWH (e. g., peer discussion, all class discussion, textbook reading, hands-on activities, SWH template writing, and letter writing); (b) how students went about the tasks of composing questions, knowledge claims, explanations, and evidence when writing; (c) how various features of the letter writing activity interacted with learning; and (d) how students would approach a novel biology problem. Interviews were audiotaped and transcribed.

Written document data were also collected for each participant including pre and post biology tests, SWH lab report sheets, and written letters. For each of these documents, sections dealing with a single topic—diffusion and osmosis through the cell membrane—were targeted. This topic was chosen because anecdotal evidence indicated a wide range in children's written explanations of these phenomena. All documents were photocopied and kept in a separate file for each student with their interview data.

The data in written form were coded according to three dimensions of analysis: (a) sources of knowledge (interview transcripts, SWH reports, and posttest essays); (b) mechanisms for increased understanding (interview transcripts); (c) correctness and incorrectness of biology explanations (SWH reports and posttests), and (d) personal epistemologies (voice) represented in biology explanations (SWH reports, letters, and posttest essays). The most frequent codes for each student were summarized. A data matrix as described in Miles & Huberman (1994) was used to compare and contrast students' learning. Memos describing the biology learning of each student were written. Through memo writing, assertions concerning the personal epistemologies (how the students learned) were created. The student profiles were then grouped according to epistemological style leading to report writing.

Results and Discussion

The Firsthand Observers

Three of 6 students revealed through their sources of knowledge, cognitive mechanisms, and nature of science explanations that they learned through their own senses. The three students included CW, MR (female and male, respectively, low achieving) and AS (male, average achieving). These 3 students most frequently cited hands-on work in the laboratory as their source of knowledge. All 3 also cited the writing of the SWH lab report as an important source of knowledge. CW cited the textbook as a third source, MR cited small-group discussion as a third source, and AS cited full-class discussion and prior knowledge as third sources. The importance of hands-on experiences for learning was expressed by AS as follows (R stands for Researcher):

R: How do hands-on activities help you learn?

AS: Because you actually see it, but like when it's in a book, it's a little bit different. When you actually see it, it's more permanent.

[Several interchanges later.]

R: How do you come up with your claims when you're doing the SWH report?

AS: Well, based on what you observed, like what happened. You can kind of see what happens. Actually see what . . . you observe, like stuff... it just sort of adds up and leads to this.

The firsthand observers all talked about the importance of actually *seeing* the phenomena as a source of understanding. As AS described, "It's more permanent." The cognitive mechanisms most frequently used by this group of students included observation, hearing the opinions of peers, and explaining. For CW and MR these were the only cognitive mechanisms coded. For AS some statements were also coded as synthesis/reflection and questioning. This group of students relied on their own observations of phenomena when writing explanations, claims, and evidence. They also felt that the cognitive act of explaining, as when writing the SWH, report was helpful:

R: Which class activities do you think are the most helpful for you to come to understand the information?

MR: The SWH's because just like the papers are, it, like, makes us rethink everything we did...It makes us rethink everything that we've learned and put it into our own words. Just put it into our own words.

The data indicate that, although the firsthand observers were considered low and average achieving students by traditional standards (the conceptual posttest and teacher evaluation), they were both cognitively and metacognitively active during class activities. Many statements made during the interviews support this claim. For example, MR demonstrated a solid understanding of the distinction between claims and evidence in science, asserting that a claim is "what you think happened" and evidence will "back up your claim":

R: If you had to define claim, what would you say it is?

MR: What happened in your own words. What do you think happened?

R: Pretty good. If you had to define evidence, what would you say evidence is?

MR: Just back up your claim. Describe why you think so. Why, why does it do that?

R: Okay. Is it hard for you to separate claims and evidence?

MR: Not really, cause they're two different questions. And evidence is why you think or what makes you think this is...claim is what you think happened.

Although MR exhibited a strong understanding of claim and evidence, CW exhibited contemplation and cognitive dissonance regarding discrepancies between her firsthand observations and information presented in the textbook:

R: You mentioned the SWH writing is confusing sometimes. Why do you think that writing the SWH is sometimes kind of difficult?

CW: Because sometimes your opinion and the book, it's, it's different and so you don't know which one is right. And so it...that frustrates me, cause I don't know which one to write down or stuff... [A couple of interchanges later, she elaborated further]

CW: Sometimes it's... like if you did it wrong, you get the wrong answer or you get the wrong lab things. I don't know. I don't know why you get like wrong info or stuff. Like, from the labs and then compared to the book, they're different. Maybe they...maybe their [textbook scientists] lenses or something are stronger than our lenses from the microscope. So when we do the lab activities, they're different. Theirs are stronger, so theirs are, like, more right than ours.

CW's personal epistemology reflected an orientation toward "believing" firsthand observations. That is, she reflected what science educators might call a positivistic stance toward drawing conclusions directly from data. Her explanation for the discrepancy between her lab findings and the textbook explanation was that the textbook authors must have more powerful microscopes. She was disturbed by this discrepancy, and trying to determine which source of knowledge to use frustrated her. Her written explanations indicated that she chose to rely on her own observations, although she believed that the textbook may be more accurate.

The data indicated that MR, CW, and AS had personal epistemologies that relied on firsthand observation of data (a naïve understanding of the nature of science). This hypothesis was further explored in their written explanations. Analysis of these explanations revealed that the 3 students advanced evidence primarily limited to what they had directly observed in laboratory. They did not attempt to integrate textbook or full-class explanations for diffusion/osmosis into their SWH reports.

Written explanations for these phenomena for the letter writing and posttest essay questions were either absent or unelaborated. Claims and explanations for a salt and sugar lab with *Elodea* for MR and CW follow:

> I think that the reason that the plant cells change is because of the different kinds of water that I used

to find out the information that I needed. It also made some of the colors darker in some of the spots, and it also made the cell wall somewhat smaller too. I think my answer is right because when we did the test it showed to me that salt and sugar can do a lot of stuff to plant cells like move the cell wall and make the plant smaller (CW)

The cell lost some water when we put the sugar and salt in. When the cell loses water so does the vacuole and the cell becomes skinny. The cell and the vacuole always have the same amount of water in them. When you put drops [sic] sugar or salt on the leaves, the cells and vacuoles suck up as much water as they can, but since the drops aren't 100% water, the cells don't get as much water as possible. When the cells are not full of water, neither are the vacuoles, so the cells go limp (MR).

These two explanations are of a different nature, but both are limited to firsthand observations and do not draw on textbook explanations. CW's claim was limited to the ideas that plant cells change when salt and sugar water are added. Her evidence is a darkening in spots and the cell wall becoming smaller. She did not attempt to explain her observations based on the theories of osmosis and diffusion. MR claimed that the cell lost water when sugar and salt were added. His evidence was that the cell becomes skinny, and he attempted to explain this phenomenon by writing that cells and vacuoles "suck up as much water as they can." Since these students did not integrate textbook knowledge and relate their firsthand observations to osmosis and diffusion canonical information, both received rather low grades on their reports. CW reported only that which she had directly observed. MR created an explanation that most would describe as "incorrect" or a "misconception," although he clearly had a partial understanding of why the "cells go limp." These students created explanations that matched their personal epistemologies of relying on firsthand observations.

The Reader

One of the students, AB (female, average achieving), could be described as a *reader* of biology knowledge. AB was unique among the participants, in that she used only textbook information and full-class discussions as her sources of biology knowledge. The majority of her cognitive mechanism codes were synthesis/ reflection. AB depended on facts, concepts, principles, and explanations that were authority based. Unlike the 3 firsthand observers, she did not use hands-on experiences or SWH report writing as a source of knowledge building. She also did not use the cognitive mechanisms of observing, hearing peers, or explaining. In short, AB disregarded the results of hands-on laboratory activities in building her biology explanations, a conscious, metacognitive decision, according to her interview data. She was the only student who disliked engaging in the SWH activities.

AB asserted that she experienced a great deal of cognitive dissonance when doing hands-on activities and trying to relate them to authoritative information:

R: So when it came down to where you actually had to write out a claim, what did you do?

AB: I just did the best I could. Like if it was for structure, I could just put the three structures and so that wasn't too hard, because I mean that's not contradicted anyway . . . But for the cell one, the question is, What processes allow materials to go in and out of the cell? And it's hard because like I don't know what to put in. Because if I just put the information from the book and our class discussions, it's going to be really short. But if I put information from the lab work, it's not going to, it's absolutely completely irrelevant to the question.

R: Why is it irrelevant to the question?

AB: Because like what we did is we had salt water and regular water and sugar water, and we would test the plant cell and the cheek cell with each and see, like, how it responded. But, like, if we describe, "Oh, the cell got bigger and was more spread out, or the cell got small and more compact," that's not explaining anything about the processes. It's just explaining what happened. And we don't know what processes caused that – the cell to react to that kind of material of those molecules.

R: But there are processes described in your book. Can you connect that with what you saw in the lab?

AB: I don't know. I could . . . I can do an experiment, but I can't make a direct comparison, cause I don't know which one [The researcher interpreted this to mean which process, e. g., diffusion, osmosis, or active transport] was used for each. Because I don't know how the cell works, because we don't have microscopes that would focus in and out to actually show, like diffusion— what's going on.

R: Well, when you look at it, would that be evidence?

AB: It probably would be more like observation, because all you're doing is observing what happened to the cell. You don't really have any evidence as to why it happened."

AB exhibited a sophisticated personal epistemology that reflected an understanding that scientific phenomenon cannot be directly explained from first-hand observations. She posited that she could describe her observations, "The cell got small and more compact," but she could not create an explanation, based upon observations alone: "I can't make a direct comparison. You don't really have any evidence as to why it happened." She did not consider what she observes to be evidence to support the theories in the textbook. She may have had the sense that since the explanation was given in the textbook, there was little authentic justification for doing the lab. The lab merely verified authoritative information that is available elsewhere and is already known to be correct. AB was more comfortable using authoritative textbook information as a source of knowledge, perhaps because she felt that was what was ultimately valued on written assignments and tests.

AB's written explanation for the osmosis lab on the SWH report, as well as in the written letter and posttest essay question, were based solely on authoritative information. The SWH report explanation was as follows:

> My claim is that the processes that allow molecules to pass into and out of cells are osmosis, diffusion, active transport, and passive transport. According to the textbook and class discussions, directed and justified by Mr. M [the teacher], diffusion (the transport of molecules from high to low concentration), osmosis (the transport of water molecules from a high to low concentration), active transport (the transport of molecules using energy), and passive transport (the transport of molecules without using energy) are the processes which allow molecules to pass into and out of a cell. (AB)

This report excerpt is clearly of a very different nature than the reports of those students described as firsthand observers. AB ventured to explain cell transport (and, in fact, identified her driving question this way) only through textbook definitions. Her evidence was based on authority, "directed and justified by Mr. M." Although AB's explanation is scientifically correct, it lacks richness and detail. Her epistemology prevented her from using authentic discourse in biology explanation.

The Integrators

The other 2 participants in the study, MF and JM (female and male, respectively, high achieving), could be described as integrators of biology knowledge. These students appeared to have an intuitive understanding of the different discourses presented in the hands-on experiments and authoritative textbook information and could negotiate between the two discourse types seamlessly. Coding their data for sources of knowledge revealed that they utilized several different types of epistemological sources in a balanced fashion. MF's sources of knowledge included SWH report writing, hands-on activities, full class discussion, textbook reading, and supplementary reading on the Internet. JM's sources of knowledge included SWH report writing, peer group discussions, full class discussions, and hands-on activities. JM described the importance of writing the SWH report for making connections between ideas:

R: What is there about writing that makes you remember it longer?

JM: Well, I think you have to make more connections when you're writing things out such as when you describe, when you have to figure out how . . . what order you're going to write things in and how you're going to connect different pieces. You think about the connection between different things that you've learned more than if you're just reading and then recording short answers that you could look up in the book.

The integrators also used a wide variety of cognitive mechanisms to process biology information. In addition to hearing peer opinions, observing, and explaining, as described by the firsthand observers, MF used hypothesizing, questioning, and synthesis/reflection frequently, and JM used synthesis/reflection, peer critiquing, and seeking evidence. Both MF and JM described how they synthesized information. For example, MF described her process of synthesis/reflection for coming to an understanding of osmosis in the following excerpt.

R: And your evidence was?

MF: My test results. I showed, I drew pictures of what the constant was with the normal tap water. And then I put two other slides from the salt water and the sugar water—those two substances. And I drew what I saw. And then I researched...researched on osmosis and diffusion. And then we had those class discussions. And that helped me, because then you also have this reading and where we compare our claims to others, that helps you.

In this excerpt, MF indicated how she negotiated among various knowledge sources. Her personal epistemology included her own personal observations, ("I drew what I saw,") and then coordinating her observations with authoritative information (MF

preferred to use the Internet in addition to the textbook to conduct her research). She particularly cited the SWH template question that asks students to compare their own findings with authoritative text, ("where we compare our claims to others") as being helpful to her in building her biology explanations. She relied on both her firsthand test results and class discussions. All sources of knowledge were integrated to form her understanding.

MF's osmosis explanation from her SWH report, demonstrates an almost seamless integration of these understandings into an authentic explanation that is rich and detailed. JM's explanation was similarly sophisticated. MF and JM score highly and were considered by the teacher as high achieving students. They may have achieved a high status because their explanations include both the rich detail of firsthand observation and the canonical explanations of diffusion and osmosis that the teacher sought.

> When a solution is added to *Elodea* plant cells the cells shrink and chloroplasts tend to move toward the center of the cell. The cell shrinks due to the method of substance movement called osmosis. Osmosis is the process of water molecule movement. When a cell is placed in an environment that has a low concentration of water molecules, the process of osmosis corrects that. Within the cell lies the vacuole and inside the vacuole is water. If the concentration of water molecules within the cell vacuole is higher than the cell's outer environment, the water molecules are released into the outer environment. The vacuole takes up the most amount of space within the cell. The vacuole pushes the cell wall helping it keep its shape, but when the water within the vacuole is released, the vacuole is deflated. The deflation of the vacuole causes the cell structure to shrink. Without the vacuole, the cell wall is not able to maintain large, rigid form it once had. Thus, the cell shrinks.
>
> When we added salt-water and sugar-water solutions to the cells they shrunk. This happened because the salt and sugar molecules take up a lot of space that is usually designated for the water molecules. With sugar and salt molecules hogging up the space, there are only a few water molecules present. The cell realizes this and since the water concentration within the cell is greater than the outside environment, the cell goes through osmosis. This could also explain the rapid movement of the chloroplasts when we added the sugar-water solution (MF).

Conclusions and Implications

The data from this study indicate that individual students used sources of knowledge that most closely matched their own personal epistemologies. Three of the students relied on hands-on laboratory activities and the accompanying small group discussions and writing about those activities as their primary way of understanding diffusion/osmosis. Correspondingly, these 3 students relied on the cognitive mechanisms of observation, hearing peer opinions, and explaining. All 3 placed value on the actual task of writing the SWH report (e.g., writing to learn) as it enabled them to put their understandings into their own words. Their written explanations were limited to what they could observe and induce on their own.

One student used primarily the textbook and full-class discussion as her sources of knowledge. She recognized the limits of firsthand observations for delineating theory and rejected her laboratory observations as evidence of theory. She preferred to rely on authoritative sources of knowledge and explained diffusion/osmosis in terms of textbook definitions. Her most important cognitive mechanisms were synthesis/reflection, but she did not extend synthesis to laboratory observations.

Two other students used almost all available sources of knowledge and a wide variety of cognitive mechanisms to construct biology explanations. They experienced little cognitive dissonance when asked to compare their firsthand laboratory observations with theories given in the textbook. They readily related scientific explanations with their own observations to create rich, detailed, correct, and authentic understandings of diffusion/osmosis.

These findings are significant and imply actions for both the direct modification of the SWH as a classroom tool and for science education, in general. The first issue to consider is how can the value of the learning that took place in this series of activities be judged? All 6 of these students were on task and, in fact, all were cognitively and metacognitively engaged. At least 1 student, MR, who received low scores on classroom measures of success (e.g., the researchers and teacher had produced thoughtful rubrics for both the SWH report and conceptual posttests), demonstrated sophisticated scientific reasoning about claims and evidence. The three firsthand observers carefully considered their laboratory findings but could not or did not choose to attempt integration with the different discourse style of the textbook. The reader conscientiously chose not

to attempt integration, and her explanation depended on textbook style language. The integrators demonstrated the skill of negotiating between these different discourse styles and, therefore, were able to create the most complete explanations. The results imply that all the students learned from the activities but that, in order for all students to achieve the conceptual understanding that was desired, explicit instruction on negotiating discourses is necessary.

Assuming that science educators want children to achieve high levels of understanding for both scientific reasoning processes (nature of science) and consensually acceptable explanations of science concepts, a series of modifications to classroom practice might include the following:

1. Including more teaching of reading and practicing meaning negotiation with the discourse of the textbook. Instruction could improve the ability of some students to read and understand authoritative text and, possibly, be open to incorporating it into their explanations. This important feature of science education is often neglected in the science classroom.

2. Explicitly teaching the different discourse styles used in science. Peer group table talk surrounding a hands-on investigation has a different nature than that of a full- class discussion, an oral presentation in class, a letter written to one's parents, or the reports and explanations found in textbooks. Teaching students how to recognize and "speak" in each of these discourse forms may be key to their ability to integrate their knowledge.

3. Adjusting grading rubrics, for both student assessment and research, so that success with scientific thinking, such as the distinction between claim and evidence, is rewarded equally with conceptual understanding. Rewarding both conceptual knowledge and knowledge of the nature of scientific inquiry would give children a more balanced sense of their scientific growth.

4. The SWH may be adjusted in the context of the classroom to incorporate these changes.

There has been much recent discussion concerning the purposes and practices of laboratory in science education (Wellington, 1998). This study supports the importance of hands-on observation in science, even for verifying established theory. Five of the 6 students used the laboratory as a source of understanding for diffusion/osmosis and for 3 of the 5, it was the primary source. Hands-on activities are an important knowledge source for students who have difficulty negotiating the meaning of the textbook. They also allow students to create richer explanations of phenomena if they are able to integrate authoritative information with what they can actually experience in lab. The reliance of students on laboratory experiences suggests that teachers should continue to teach science with laboratory, but with more instruction aimed at clarifying the different discourses used in science and helping children negotiate these various discourses.

References

Edmonson, K. M., & Novak, J. D. (1993). The interplay of scientific epistemological views, learning strategies, and attitudes of college students. *Journal of Research in Science Teaching, 30,* 547-559.

Galbraith, D. (1992). Conditions for discovery through writing. *Instructional Science, 21*, 45-72.

Halliday, M. A. K., & Martin, J. R. (1993). *Writing science: Literacy and discursive power.* Pittsburgh, PA: University of Pittsburgh Press.

Hogan, K. (1999). Relating students' personal frameworks for science learning to their cognition in collaborative contexts. *Science Education, 83,* 1-32.

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). *Journal of Research in Science Teaching, 36,* 1065-1084.

Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching, 37,* 676-690.

Klein, P. (1999). Reopening inquiry into cognitive processes in writing-to-learn. *Educational Psychology Review, 11*, 203-270.

Klein. P. (2000). Elementary students' strategies for writing-to-learn in science. *Cognition and Instruction, 18*(3), 317 - 348

Mason, L., & Buscolo, P. (2000). Writing and conceptual change: What changes? *Instructional Science, 28*, 199-226.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: A sourcebook of new methods* (2nd ed.). Newbury Park, CA. Sage Publications.

Millar, R. (1998). Rhetoric and reality: What practical work in science education is *really* for. In J. Wellington (Ed.) *Practical work in science: Which way now?* New York: Rutledge.

Novak, J. D., & Gowin, R. (1984). *Learning how to learn.* Cambridge: Cambridge University Press.

Rivard, L. P. (1994). A review of writing to learn in science: Implications for practice and research. *Journal of Research in Science Teaching, 31*, 969-983.

Rivard, L. P., & Straw, S. B. (2000). The effect of talk and writing on science learning: An exploratory study. *Science Education, 84,* 566-593.

Tsai, C.-C., (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education, 82,* 473-489.

Tsai, C.-C. (1999). "Laboratory exercises help me memorize the scientific truths": A study of eight graders' scientific epistemological views and learning in laboratory activities. *Science Education, 83,* 654-674.

Wallace, C.S.., Yang, E. M., Hand, B., & Hohenshell, L. (2001, March). *Using the science writing heuristic to enhance learning outcomes from laboratory activities in seventh grade science: Quantitative and qualitative aspects.* Paper presented at the annual meeting of the National Association for Research in Science Teaching. St. Louis, MO.Wellington, J. (Ed.). (1998). *Practical work in school science: Which way now?* London: Routledge.

Editors' Note: Correspondence concerning this article should be addressed to Carolyn S. Wallace, Science Education Department, 212 Aderhold Hall, The University of Georgia, Athens, GA 30602-7126.

Electronic mail may be sent via Internet to wallacec@uga.edu

Appendix

The Science Writing Heuristic: Teacher and Student Templates

Teacher Template

1. Exploration of pre-instruction understanding through individual or group concept mapping.
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions.
3. Participation in laboratory activity.
4. Negotiation phase I- writing personal meanings for laboratory activity (For example, writing journals).
5. Negotiation phase II- sharing and comparing data interpretations in small groups (For example, making a group chart).
6. Negotiation phase III-comparing science ideas to textbooks or other printed resources (For example, writing group notes in response to focus questions).
7. Negotiation phase IV- individual reflection and writing (For example, writing a report or textbook explanation).
8. Exploration of post instruction understanding through concept mapping.

Student Template

1. Beginning Ideas —What are my questions?
2. Tests— What did I do?
3. Observations— What did I see?
4. Claims — What can I claim?
5. Evidence— How do I know? Why am I making these claims?
6. Reading — How do my ideas compare with other ideas?
7. Reflection – How have my ideas changed?